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Advancing Coral Reef Governance into the Anthropocene

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The unprecedented global heatwave of 2014-2017 was a defining event for coral reefs. Widespread degradation caused by coral bleaching highlighted the vulnerability of hundreds of millions of people dependent on reefs for their livelihoods, well-being and food security. Policymakers are reassessing long-held assumptions about coping with anthropogenic climate change, particularly the conventional supposition that strong local institutions can maintain ecological and social resilience through ecosystem-based management, adaptation, and restoration. Current governance is struggling to address the new normal, as reef assemblages transform to novel configurations. A central challenge for policymakers in the Anthropocene is navigating environmental crises and resource insecurity, and coping with societal conflict and change. Ecosystem governance needs a new paradigm to embrace rapid change and shape future trajectories. In this Perspective, we explain the spatial, temporal, and political dynamics of reefs as they respond to climate change, and outline a new alternative governance paradigm applicable to all ecosystems.

The unfolding crisis in coral reefs will have profound environmental, economic, social, and cultural consequences for both biodiversity and for reef-dependent societies (IPCC, 2018). Reefs provide critical ecosystem services such as fisheries, tourism and shoreline protection, that are essential to the social and cultural fabric of maritime tropical societies (Teh et al. 2013; Donner at al 2007; Moberg and Folke 1999). The Intergovernmental Panel on Climate Change (IPCC) Special Report warns that many coral reefs will struggle to cope with future global average temperatures of 1.5°C to 2°C above pre-industrial levels. With 1°C of global average warming so far, 94% of coral reefs have already experienced one or more episodes of severe coral bleaching since 1980 due to record-breaking temperature extremes (**Figure 1**). The urgent need to protect coral reefs has prompted a range of interventions, including not just global agreements to reduce greenhouse gas emissions, but also additional marine protected areas, extra pollution control, coral gardening programs, and even geoengineering programs (Darling and Côté 2018; National Academies of Sciences 2018; Van Hooidonk et al. 2016). Central to these efforts is an improved understanding of the governance that enables intervention success.

In this Perspective, we argue that a new governance paradigm is required to sustain coral reefs under climate change. First, we examine the new challenges for governing reefs in the Anthropocene. Second, we consider whether current governance paradigms are enabling interventions appropriate to the task. We caution that some interventions, despite good intentions, have the potential to form a governance trap for coral reefs, because they fail to address the contemporary root causes or the political dynamics of coral reef degradation. Third, we interrogate the conventional framing and scaling of reef governance. We argue that a narrow focus on local and biophysical interventions can distract from the multiscale political dynamics (including political legitimacy and societal conflict) that must be overcome in order to save reefs at a meaningful scale. Fourth, we develop a conceptual agenda with potential to advance understanding of interactive and cross-scale interventions and effects on reef trajectories. Last, we explore a series of emerging solutions that offer hope for reef ecosystems and reef peoples. We emphasize that, for reefs to survive the Anthropocene, coral reef governance can and must move beyond conventional framings and scales of local conservation. We show how scientists and policymakers must expand their focus, enabling multiscale and forward-looking science and policy to sustain all ecosystems.

Contemporary governance is failing

Until very recently, reef governance, and ecosystem governance in general, has operated according to an established paradigm that strong local management can maintain ecological and social resilience through collective intervention in proximate stressors (e.g. over-harvesting and pollution) and restoration. Under this paradigm, ecosystem governance has focused on maintaining biodiversity or restoring social and ecological systems to historical baselines (Ostrom 1990; Foley et al. 2017). However, the escalating impacts of climate change are evidence that this paradigm is no longer tenable for coral reefs and many other ecosystems (Hughes et al. 2017, Bellwood et al 2019).

Regional and pan-tropical coral reef bleaching events are occurring more frequently, challenging the capacity of reefs to recover between extremes (Hughes *et al.* 2018). A dynamic new normal is emerging, as reef species respond to altered disturbance regimes that now include episodic climate extremes. The biodiversity, species abundances, physiology and genetic composition of corals and associated species is shifting. Furthermore, stock-recruitment relationships and larval dispersal are changing, creating new networks of connectivity among reefs (Hughes et al. 2019). Many individual species are expanding into sub-tropical seas (Verges et al. 2019). As species acclimate, evolve and disperse, reefs in the Anthropocene are dominated by tougher, thermally-tolerant survivors or by weedy, fast-growing species that are quick to recolonize (Edmunds et al, 2014, Hughes et al, 2018).

Interacting pressures from climate change, overfishing and pollution are escalating. These proximate drivers of degradation of coral reefs are themselves driven by changing patterns in expanding global markets, unfetterred regulation of resources and polluters. The combined impacts of these stressors is already affecting reef-dependent communities, especially in small and poor island states (for example, the Solomon Islands, Micronesia and Fiji) (Karasik et al. 2019). Coral reef degradation combined with sea level rise and increased natural disasters, is leading to depletion of fish stocks, salinization of aquifers and loss of land. In the Pacific, vulnerable Small Island Developing States (SIDS) are experiencing accelerated saltwater intrusion of their freshwater supplies and inundation by sea level rise. These changes pose significant risks to land, food and water security (Willett et al. 2019; Belmar et al 2016) -

especially for populated and agriculturally rich coasts. In many places, increased conflict over basic land, food and water resources (Spijkers et al 2018), and migration triggered by climate change, have the potential to aggravate existing social problems of poverty, urban crowding and disease (Savage 2019; WHO 2018).

Helping reefs and reef peoples to navigate these challenges is a major challenge for governance. Governance is broader than government and incorporates the overarching structures and processes for creating knowledge about coral reef degradation, prioritizing issues, formulating policy, delegating responsibility, and making decisions about how to intervene. The intergovernmental agreement that led to the creation of the Great Barrier Reef Marine Park Management Authority (GBRMPA) in 1975, for example, and later enabled the successful and highly awarded rezoning of the Great Barrier Reef Marine Park in 2004, remains an example of effective ecosystem governance (Morrison 2017). However, the recent multi-year global marine heatwave of 2014-2017 has now confounded established scientific and policy understanding of what constitutes effective ecosystem governance. Newly published studies are exposing governance time lags, governance mismatches, and ultimate governance failure. UNESCO's reporting on climate change impacts for 29 World Heritage listed coral reefs, for example, has been shown to have lagged the observed impacts by close to a decade (Box1; Morrison et al 2019a). New analysis of 40 years of GBRMPA Annual Reports highlights a continuous pattern of mismatches between threats identified by the agency and subsequent management goals, as well as mismatches between management goals and subsequent management interventions (Bellwood et al 2019). Recent independent assessments for the Great Barrier Reef and 28 other World Heritage listed coral reefs (GBRMPA 2019a, Australian Government and Queensland Government 2019; Heron et al 2018) now demonstrate that even the most remote, best-managed and pristine reefs are vulnerable to global heating (Fig. 1) (Eakin et al. 2019). Ecosystem governance – that is, the policy, politics, science and administration that enables effective ecosystem management – is straining in the face of climate change. The challenge now is to develop an alternative governance paradigm, one that is up to the task of sustaining reefs in the Anthropocene.

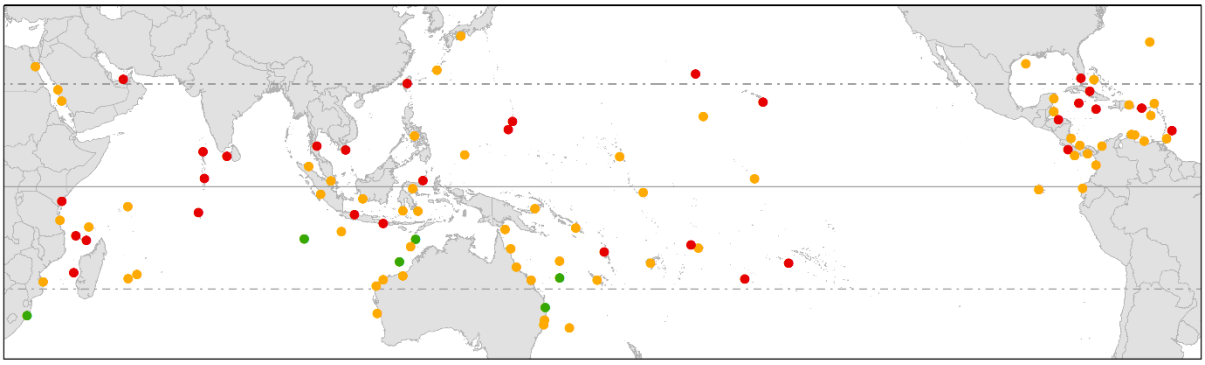


Fig. 1 Extent and frequency of coral bleaching since 1980. One hundred reef locations were assessed for severe bleaching events each year from 1980-2017 (Hughes et al. 2018), affecting >30% of coral colonies. Green, orange, and red reef locations have already bleached 0, 1-3, or 4 or more times, respectively by severe bleaching.

Understanding ecosystem governance dynamics

Reducing greenhouse gas emissions is critical for arresting the degradation of all ecosystems across the globe (IPCC, 2018). However, in the case of tropical reefs, well-intentioned scientists and policymakers have begun to experiment with and advocate for a wildly

expanding suite of interventions, ranging from business-as-usual at one end, to GHG mitigation, ecosystem-based interventions, land-sea planning, bioengineering and even geoengineering interventions at the other. Contemporary governance focused on local conservation is incapable of overseeing and making sense of these current and proposed interventions. For a start, contemporary governance unfairly places the burden of restoration or maintenance onto local reef managers and users, rather than on other parts of society responsible for broad-scale drivers of reef degradation. Furthermore, contemporary governance actors are powerless to oversee the complicated decisions that need to be taken at much higher scales in order to ultimately arrest reef degradation. Such oversight is crucially important, because without it, reef outcomes will be determined by uneven politics and power dynamics (Morrison *et al.* 2019b), rather than fair and democratic processes (?).

More than the sum of the parts

A tranformed governance paradigm for ecosystem intervention entails thinking very critically about what trajectory ecosystems need to be on and what kind of interventions might enable that desired trajectory (Steffen et al. 2018; **Figure 2**). Ecological and political science theories on intervention intensity and synergy hold much promise for a more effective approach to ecosystem intervention (Rogge and Recihardt 2016; Schaffrin, 2015). For example, no intervention – that is, business as-usual - will lead to a degraded ecosystem state. Medium-intensity intervention – that is, conservative and incremental adjustments – could buy more time. High-intensity interventions, by contrast, entail step-change - that is, transformative change - to sustain ecosystems into the future.

Interventions should ideally address the root cause of the problem, rather than whether whether they are future-oriented, evidence-based, and politically acceptable (Wildavsky 2017). The overall advantages and challenges of the mix of interventions also needs to be assessed holistically (Howlett et al. 2015). In considering the intervention mix, both primary and secondary outcomes must be considered. This is because preferred interventions not only have on-the-ground outcomes, they can also lock-in scientific and policy outcomes, which can ultimately effect ecosystem outcomes in a more profound way into the future (Bellamy and Healey 2018). In essence, a more appropriate governance paradigm does not valorize local conservation, rather it: 1) analyses the range of proposed interventions for coral reefs, according to their intensity, future-orientation, evidence base, and political acceptability; 2) interrogates how interventions work together as a group and in sequence; and 3) assesses the broader scientific and policy implications of a particular intervention and groups of interventions.

To illustrate: governance that endorses business-as-usual emissions of greenhouse gases and increasing local stressors will see coral reefs cease to exist by 2070 (IPCC 2018). Despite scientific projections, passive business-as-usual remains a popular short-term response in many reef nations. By contrast, global agreements, specifically the 2015 Paris agreement, recognise that for coral reefs to have any viable future, global society must mobilise to meet the climate mitigation challenge. The pathway to zero net emissions means reducing global carbon emissions by 45% below 2010 levels by 2030 (IPCC, 2018). Notwithstanding genuine leadership by some governments, NGOs, community groups, and individuals, global mitigation ambitions have been hampered by many challenges, including divergent capacities for change, short-term economic interests, carbon lock-in, and sustained public misinformation campaigns (Creutzig 2019; Nyberg and Wright 2019).

Ecosystem-based interventions, on the other hand, are designed to address local reef stressors through marine protected areas, management of fisheries, and water quality management (Roberts et al. 2017). Ecosystem-based interventions remain popular because less fished and/or polluted reefs are more likely to recover quickly between episodic bouts of mass-bleaching caused by rising temperatures (Hughes et al. 2007). However, these interventions rarely address the root causes of overfishing or pollution, for example poverty, market-demands, or corruption. Nor do they prevent global heating or ocean acidification. Furthermore, the effectiveness of marine protected areas and fisheries management is highly dependent on local support and compliance (Kuempel et al 2019; Turner et al 2016).

Bold land-sea interventions seek to extend ecosystem-based actions (?) by integrating marine approaches with terrestrial-based investment in renewable energy, fossil fuel divestment, land-based aquaculture, and carbon sink restoration. Land-sea programs draw on a long history of comprehensive land-use planning dating back to the Tennessee Valley Authority in the 1930s in the USA (Morrison et al 2015). Today, land-sea interventions are being promoted by transnational partnerships, international aid agencies, and major social movements across the world, including the Coral Triangle Initiative, the Global Environment Facility, and the Green New Deal movement (Morrison et al 2019a). However, local opposition, corruption, and a lack of resources can hamper these efforts (Kolstad and Søreide 2009). Further, contemporary aversion to top-down interventions means that bold land-sea planning will be difficult to implement without a clear vision, leadership and social acceptance of the radical changes needed to avoid dangerous levels of climate change by mid-century.

Bio-engineering interventions include small-scale coral gardening and in vitro breeding of climate-resistant corals. These interventions are popular with many well-intentioned actors (NAS 2018; Australian Government 2018); however, they are challenging to scale up beyond reseeding one or two species in small plots (Bayraktarov 2019). To date, few restoration attempts have adequately monitored the medium-term (>5 years) outcomes of planting juvenile corals or branch fragments. Unless the underlying causes of coral decline are addressed, the local history of episodic and chronic mortality is likely to repeat itself and continue. Typically, restoration attempts lack a control – adjacent reef areas that are monitored for natural recovery - hindering a rigorous assessment of the cost-effectiveness of restoration efforts. Laboratory breeding and genetic engineering of new coral strains, so-called super corals, will bring new ethical challenges and risks of unexpected outcomes (Wolfenbarger and Phifer 2000). Furthermore, it is unclear whether the release of new genotypes could change the gene pool of much larger wild populations that are already under intense natural selection from major bleaching events. Most importantly, bioengineering interventions tend to assume that restoration to past ecological conditions and past levels of biodiversity is still possible. We now know that this is not possible.

At the more extreme end of the spectrum are geoengineering interventions, which range vastly in scale from local attempts to protect corals from spikes in temperature (by cooling or shading), to radical interventions that could alter the Earth's climate system at a regional or global scale (Flegal et al 2019). Proposals like solar radiation management remain mostly hypothetical, and will be dogged by significant governance challenges, including the lack of a multilateral geoengineering agreement; the potential for unilateral action by individual states; and lack of risk assessment and management frameworks (Pazstor et al 2017). Many geoengineering proposals also convey a false promise: that it is possible to address ecosystem decline by curbing rising temperatures without dealing with the drivers causing those rising temperatures.

Governance traps and placebo policies

Each of the interventions canvassed above varies according to its intensity in addressing the root causes of coral reef degradation. Each intervention also varies according to future-orientation, evidence base, and political acceptability. However, when some interventions are promoted together as a group, they risk forming a governance trap. A governance trap occurs when the ability to address the problem (i.e. ecosystem degradation) becomes constrained by a misdiagnosis of the nature of the problem, and a miscalculation of the social actors responsible for its solution (Bernstein and Hoffman 2019; Newell 2015). For example, when some low intensity solutions are promoted together as the primary solution (NAS 2019), they reinforce the idea that it is possible to address ecosystem degradation without addressing the long-term and often distant drivers of reef decline (Fig. 2).

There are broader scientific and policy implications for ecosystems ensnared in a governance trap. For example, the Australian government has recently funded a US$65 million restoration program to restore corals on a few hectares of the Great Barrier Reef in the aftermath of mass mortality caused by record-breaking temperatures in 2016 and 2017 (Australian Government 2018), while also subsidizing expansion of fossil fuel extraction and shipping in the wider catchment. The reef restoration program is essentially a placebo policy (McConnell 2019), which allows the Australian government to escape the trap by being seen to 'do something' (research on restoration), rather than dealing with the much tougher task of addressing the deeper causal drivers of the problem (action on climate mitigation). Placebo policies are problematic because not only do they mask inaction, they also induce scientific and policy blindness to the complete range of interventions that might be possible.

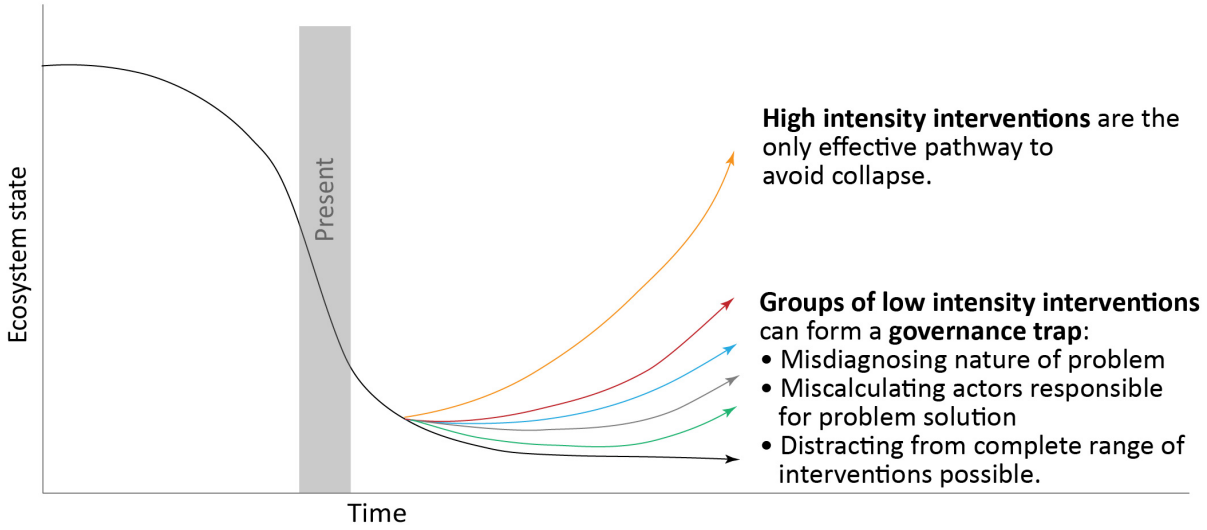


Fig. 2 Future coral reef ecosystem trajectories.

Escaping the governance trap

Effective governance is important because it enables successful management of coral reefs, that is, the day-to-day business of implementing interventions in coral reefs. While some reef actors are still proposing small-scale interventions for coral reefs, others are acknowledging and responding to the new normal of a hotter, more connected and yet more polarized world (GBRMPA 2019b). Carbon-pricing and land-sea interventions, for example, do directly address climate mitigation, are forward-looking, and evidence-based. However, these solutions

are constrained by political dynamics including public legitimacy concerns and unresolved conflicts of interest. Overcoming these challenges is critical, because the climate challenge is not just a biological or social problem but a political task (Green and Hale 2017; Javeline 2014; Keohane 2014).

How do concerned scientists and policymakers escape the governance trap? In modern liberal democracies, governing is no longer confined to the vagaries of a monolithic state. Therefore, any actor (policymaker, scientist or manager) who is either experimenting with or advocating for a particular intervention is a governance actor. The research that they choose to support, or the intervention that they choose to endorse, fundamentally affects how the broader community of scientists, policymakers, funders, philanthropists, resource managers and citizens think. This immense responsibility for shaping the broader scientific and policy landscape is further complicated by the temptation to jump to the next novel intervention. We are not implying here that new local interventions or new technologies are a waste of time, rather that such interventions need to also be assessed against a more progressive governance paradigm, and developed in conjunction with efforts at higher scales. More broadly, all actors need to step back and improve how they approach the problem of coral reef degradation in their day-to-day work, whether that be biophysical science, social science, policy or management. We believe that this paradigm shift can be achieved by 1) improving how all governance actors frame and scale the coral reef problem, and 2) harnessing broader experiments across social, ecological, economic, and policy science and practice.

To liberate future coral reefs from today's governance trap, scientists and policymakers must first begin to radically reframe and rescale. Framing is the way scientists and policymakers explain and understand ecosystem decline. For coral reefs, the dominant frame today is loss of reef biodiversity. Scaling is the way we explain the geographic coverage and timespan of the solution. For coral reefs, the dominant scale is still at the local-ecosystem level, as understood over a medium-term (>5 years) timescale.

Consistently framing coral degradation as a biological rather than a socioeconomic challenge is problematic, because this framing privileges biological and technological interventions (such as LarvalBot, the tethered robot that disperses coral larvae on 3 hectares of the 35 million hectare Great Barrier Reef), and ignores higher-scale social and economic interventions. Likewise, scaling coral degradation as a local problem privileges local solutions and reinforces the idea that non-local drivers are exogenous and therefore ungovernable. In Australia, for example, the Great Barrier Reef Marine Park Authority takes full responsibility for most activities undertaken within the boundaries of the marine park, but continues to overlook a legislative clause that potentially allows the authority to manage pollutants flowing into the reef from adjoining river catchments or to control development of coal shipping ports (Morrison 2017). In Pacific atoll countries, where climate loss and damage due to coral bleaching and sea level rise is the new normal (Barnett 2017; Mechler and Schinko 2016), international interventions remain framed around ad-hoc local marine conservation and human migration interventions, rather than the long-term adaptation planning required to sustain the highly fortified and reclaimed coastal socioecological systems that are now emerging (Barnett and McMichael 2018).

Framing and scaling can also work in ways that are more subtle. For example, as more and more ecosystems have been degraded due to climate extremes, some governments, such as the USA, have worked to deny, suppress or downplay information about the role of climatic change in ecosystem degradation, thereby hindering political support for reduction of emissions

(Lubchenco 2017). A growing body of evidence highlights that the terminology and the images that define climate change shape the way it is understood and acted upon (Chapman et al 2016; Wang et al 2018; O'Neill 2019). A number of large scientific and media organizations (such as the Science Media Centre, The Guardian and the BBC) are therefore beginning to rethink their communication of climate-impacted communities and ecosystems, including terminology and visual imagery.

For scientists and policymakers, considered framing and scaling of a problem is something that needs to be undertaken as soon as a research problem (or a policy problem) is identified. For example, scientists have highlighted the need to shift intervention away from the maintenance of charismatic fish stocks and coral cover toward maintenance of the more abstract ecosystem functions that sustain reefs, and the services we require from them (Hughes et al. 2017; Bellwood et al. 2019). Clearly, identifying these functions and services is only part of the task; selling the need to manage them in that way that resonates with communities and policymakers requires careful framing. Further, as ecosystem functions change in the Anthropocene, scientists need to be careful to appropriately scale the cause of the problem (climate change and other anthropogenic drivers), rather than the symptom (e.g. changing compositions of species). Evolving understanding of resilience now recognizes that the objects of governance should be at much higher scales (Cumming et al 2017). How we construct scalar frames about environmental change and resilience not only sends a powerful message about how we should respond to reef degradation, but about who is accountable and responsible for that response (Morrison et al., 2017).

Rapid and uncertain exogenous threats, and globally uneven power relations and development patterns, are already confounding the dynamics of ecosystem governance in the Anthropocene. Increasingly, we face a fundamentally different reality: it is no longer possible for local institutions to ensure ecological and social resilience through local ecosystem-based management, adaptation, and restoration. For example, as the impacts of adjacent coal and gas development and climate change have come to fruition, governance of the Great Barrier Reef is evolving from a local assemblage dominated by fishing and tourism stakeholders to a complex polycentric regime including mining lobbyists, UNESCO and large international ENGOs (Morrison 2017). Similarly, as coastal ecosystems in the Pacific become rapidly fortified and reclaimed, governance of these systems now involves not only ENGOs and the ecotourism industry, but also coastal engineers, human migration agents, and transnational authorities. Governance for local conservation and traditional livelihoods is no longer enough – it must evolve to reflect these current and future realities.

One important new way of thinking about ecosystem degradation is to consider the interactions between multiple interventions. Interventions are antagonistic if they weaken or block one another, so that the combined effect is less than the sum of the individual effects. For example, Australia has multiple policies for protecting the Great Barrier Reef, but also seeks to expand fossil fuels, coal and gas ports and shipping. Additive effects occur when actions simply co-exist without affecting each others' outcomes for better or worse, and therefore the combined effects are equal to the sum of the individual effects. An example of an additive effect is where a government adopts an environmental regulation which an industry has already voluntarily adopted and even exceeded (e.g. regulation of ecotourism). Synergistic outcomes occurs when one policy, law or management intervention has a reinforcing effect on another, so that the combined outcomes exceed the individual effects (Nilsson et al 2016; Morrison 2014). Combining economic (e.g. debt alleviation) and social (e.g. public health) interventions with ecological interventions (e.g. to reduce pollution), for example, can synergistically build both

social and ecological resilience (Wear 2019). However, synergistic interventions not only require scientific evidence and modelling, they also require a moral case, political legitimacy and economic incentive.

Political economy of change

Synergistic interventions are part of the paradigmatic shift that is required to move from a sole focus on collective action at either the ecosystem level or the global level to a much more multiscale and interactive approach, comprising diverse interventions at multiple scales. In recent years, theoretical and empirical studies have provided a robust framework for understanding multiscale or polycentric responses to climate change. For example, it is now widely recognized that polycentric governance comprises multiple governing authorities at different scales that do not stand in hierarchical relationship to each other but are engaged in self-organisation and mutual adjustment, and that polycentric governance is more than just networks of actors, it also includes non-structural qualities. However, considerable gaps in our knowledge remain - in particular how to harness the untapped sources of power that exist within and between cross-scale actors and interactions in order to sustain coral reefs.

Emerging research is showing how coral reefs are central to conceptions of identity and community, and how loss of reef leads to measurable and real loss of well-being (Marshall et al., 2019; Cunsolo and Ellis 2018). Such identification and emotion is not only felt by individuals intimately connected with reefs on a day-today basis, but by populations far away from reef locations (Gurney et al 2017). For example, charismatic and stunningly beautiful coral reefs continue to feature as the totem of many climate protests worldwide. Scientists and policymakers are beginning to focus on how such social movements are formed, and how views of coral reef dynamics are framed, maintained, and changed through such movements (Tekwa et al 2019; Hayward et al 2019). Other scientists are paying closer attention to multiple distant drivers of change (for example, reef supply chains to distant markets) (Fabinyi et al 2017; Munroe 2019). Some of those scientists are working with so-called keystone actors (e.g. powerful companies, nation states and/or regional governments) to modify their interactions to mitigate against climate change and reduce proximate stressors, whether through diplomacy, trade, and/or information and technology exchange (Osterblom et al 2017). Such activity has an expanding effect in that it increases the moral pressure and economic incentive of less powerful actors to support sustainability initiatives, with benefits for all ecosystems, including coral reefs (Creutzig 2019). Identifying and targeting such untapped sources of power offer fresh opportunities to underscore the moral dimension of the climate crisis, while also opening debate and deliberation to a much broader set of societal actors (Schlosberg et al., 2017).

Decarbonization and adaptation

To sustain ecosystems and people into the next century and beyond, we need a smarter governance paradigm, one that is fit for the Anthropocene. Building on emerging understanding of the effect of intervention intensities and synergies on ecosystem trajectories, we propose two complementary approaches to this endeavor.

First, decarbonisation rather than conservation needs to be understood as the defining challenge for coral reefs (Bernstein and Hoffman 2019). Decarbonisation is the process of disrupting fossil energy dominance so that it eventually becomes only a small part of the energy mix. So far, reef conservation has been heavily influenced by commons and collective action theory, which still emphasizes reefs and reef-dependent peoples as the single arena for action. We now

know this is inadequate. Changing perspective to consider the challenge of decarbonisation opens up a much wider variety of multisectoral strategies for coral reefs, including multiscale political, economic, technological and cultural strategies (Green 2018). Consider, for example, the self-funding system of renewable energy in Fiji, which has been recently installed by the Fijian Government in partnership with the Leonardo DiCaprio Foundation, the Fiji Locally Managed Marine Area Network and private energy companies. This potentially transformative intervention is improving livelihoods, reducing emissions and increasing climate resilience for Fijian coastal communities (Republic of Fiji 2018). Understanding how this intervention and similar interventions could spur specific reef systems to escape the governance trap can help create new framings for action and responsibility for reefs, and spread transformation throughout reef systems, with benefits not just for reefs but for all ecosystems.

Second, innovative forms of adaptation planning could also provide opportunities to induce disruption and transformation. Despite rising acknowledgement of climate impacts and the need to manage reefs for ecosystem function and resilience, adaptation planning is still lagging for most reef systems (Bellwood et al 2019). Where it does occur, it is typically restricted to adaptive management (such as permitting systems which reflect fish stock changes) and generally does not consider broader adaptive capacity (Cinner et al 2018) nor emerging social, technological, political and economic trends. In SIDs such as Kiribas, the Marshall Islands and the Maldives, for example, rapid fortification and reclamation to adapt to rising seas is eclipsing conventional marine tourism and conservation strategies. A variety of novel theories (e.g. behavioral priming) and social engagement tools (e.g. participative scenario-building, foresighting, futures prototyping) can enable scientists and policymakers to explore how different conditions, drivers and decisions shape pathways towards alternate visions of the future (Curato et al., 2017; Barnett et al. 2014, Berkhout et al 2014). Adaptation planning is therefore essential to building adaptive capacity to navigate emerging conflicts and potentially maladaptive interventions (Blythe et al 2018). Understanding decarbonisation and adaptation planning as part of the intervention mix will be integral to addressing the escalating problems that confront coral reefs (**Figure 3**).

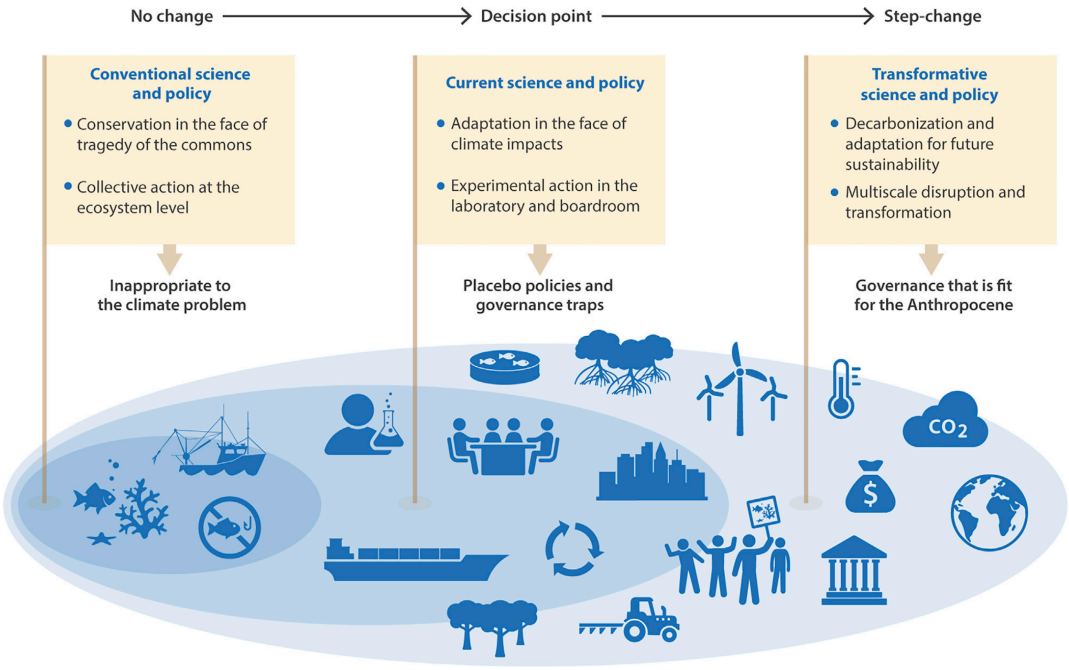


Fig. 3 Conventional, current and smarter interventions in the broader coral reef system under climate change

Hope in the Anthropocene

Arresting coral reef degradation is a monumental global challenge. Equally monumental social and environmental challenges have been overcome in the past through a variety of means, including social sanctioning (smoking in public places), community norm change (fertility control), and global agreement (CFC control) (Haas et al 2019; Nyborg et al 2016). Such interventions have steered social and ecological systems away from feared trajectories of pollution, overpopulation and ozone depletion toward more sustainable trajectories. A series of similar interventions are now emerging which offer hope for reef ecosystems and reef peoples.

The Alliance of Small Island States, for example, is a collation of 44 low-lying and small island states that share common concerns about oceans and islands. This broad coalition has opened new policy windows, influenced government action, and mobilized additional resources to address impacts of climate change on reefs and reef peoples (United Nations General Assembly 2014). Through their collective action in the United Nations system, for example, they have increased international pressure to set and meet the ambitious 1.5oC Paris target (Benjamin and Thomas 2016).

Other authorities are also helping to create collective action across the world to mitigate emissions, facilitate adaptation, and propose policies and measures addressing coral reef degradation. The United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Centre, for example, has improved reporting on the vulnerability of individual World Heritage listed reefs to climate change (Box 1, Heron et al 2018). Established in 1972, the WH Convention is widely regarded as one of the world's most powerful global environmental regimes, ratified by 192 countries. While some countries (including Australia) have resisted moves by UNESCO to consider climate mitigation within the World Heritage

framework (Oxley 2019), other countries (including the United Kingdom) have responded to the WHC's powerful messaging and begun to systematically assess vulnerability of World Heritage listed properties to climate change. Those countries are now developing proactive mitigation and adaptation plans (Day et al 2019).

The Nature Conservancy, along with many other environmental non-government organizations, is beginning to adopt synergistic interventions that aim to benefit both people and nature. For example, major conservation interventions are now evaluated (and therefore re-framed) using multiple metrics, including: number of people benefiting from ecosystem-services (Reguero et al. 2018), metric tons of CO2e/year sequestered (Griscom et al. 2017), increased equity, number of fisheries with improved management, increased food production and security, and area of land or sea protected (Tallis et al 2018). Other partnerships between governments, development institutions, and philanthropic foundations (e.g. through the Consultative Group for International Agricultural Research) are also beginning to champion cross-sectoral interventions to climate mitigation and adaptation, especially focused on food security in the Pacific (Rawe et al 2019).

Similarly, the Global Environment Facility - an international partnership of 183 countries, international institutions, civil society organizations and the private sector – has set up a Pacific Ridge to Reef Programme to simultaneously reduce global emissions and pollutant runoff and promote sustainable energy and food production in 14 Pacific island nations (Granit et al 2017). Non-government organizations are also experimenting with different funding schemes to increase the scale of interventions (including crowd-funding, debt conversions, reef insurance and other payments for ecosystem services) (Beck et al. 2018; Gallo-Cajiao et al. 2018). New public-private green economic stimuli also hold much promise for reinforcing multiple outcomes.

These developments are not exhaustive, and many of them require a fundamentally different mindset from the current paradigm. The potentials and limits of these developments as a means to save coral reefs are also not yet fully understood. Key opportunities we have not engaged with here but which require continued study include the role of new technologies, such as geo-visualization and new media, new youth coalitions, and human emotion as an untapped force for political change (Hulme 2019). Active communication and collaboration between the biophysical sciences, the social sciences and the humanities will be critical to this endeavor.

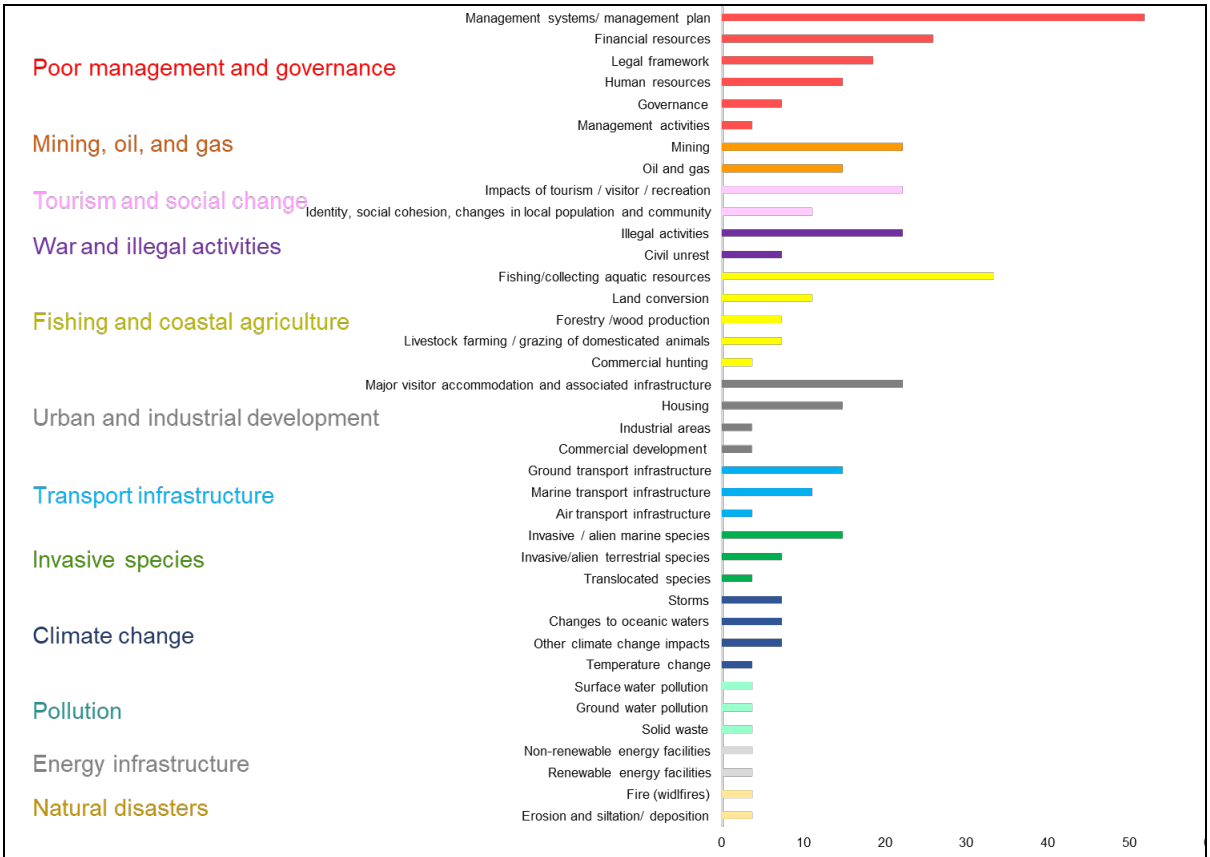
Governance futures

Coral reef ecologists have comprehensively demonstrated how a combination of anthropogenic thermal stress, pollution, and overfishing collectively degrades reefs. Biological and climate scientists have also documented that most drivers of ecological change are increasing. Environmental social scientists have demonstrated that people, politics and institutions matter. A developing research and policy agenda is beginning to extend these perspectives to incorporate and further develop recent political, cultural, and social innovations. Consequently, a new reef governance paradigm is emerging, which is expanding understanding and – potentially - accountability**.**

To liberate future coral reefs from today's governance trap, scientists and policymakers must continue to radically reframe and rescale. This paradigm shift is necessary to test the political legitimacy and effectiveness of proposed interventions, to measure political feasibility and modify interventions accordingly, and to guide the development of completely new

interventions that are often overtly political. Indeed, securing a future for coral reefs under climate change is a political challenge as much as an ecological or social challenge. Understanding how to manipulate ecological, social AND political dynamics at a variety of spatial and temporal scales is now integral to addressing the escalating problems that confront coral reefs. While the scientific hurdles (interdisciplinarity, complexity, normativity) of the new paradigm are challenging, we believe that the benefits will be gargantuan.

Box 1. Threats outpacing governance of 29 World Heritage listed coral reefs



As the threats to ecosystems grow in scale and frequency, they are outpacing conventional institutions, laws and governance. 29 coral reefs globally are governed under the 1972 UNESCO World Heritage Convention, including reefs in the Galapagos, Australia and Hawaii. The first World Heritage listed coral reef bleached in 1979, before inscription, but climate reporting did not commence until 1991. Since then, the number and frequency of bleaching events has increased over time (Hughes et al 2018). Today, 23 out of the 29 coral reef sites are reported as affected by climate change.

UNESCO reporting on climate change has also steadily increased – mainly due to a series of ENGO petitions - but still maintains a significant time lag (Morrison et al., 2019a). UNESCO has traditionally shied away from seeking to influence non-local threats, effectively delegating responsibility to other conventions (e.g. UN Framework Convention on Climate Change). Understanding and reporting of the cumulative effect of different threats also remains poor (UNESCO 2016).

Recent trends and events (such as glaciers melting in ecosystems in North America and Europe, and coral reefs bleaching in Australia and across the tropics) are now motivating UNESCO to reconsider the challenge of maintaining Outstanding Universal Value under climate change (Heron et al 2017). UNESCO recognised in 2017 local level action is not enough to tackle the critical threat of climate change, and is currently preparing a new policy for climate change and World Heritage. One solution is that national policies for climate change are taken into account in World Heritage decision-making, which could form part of the revised climate policy to be presented at the 44th WH Committee meeting in Fuzhou, China in 2020. Such unconventional and inherently political solutions could prove critical to sustaining coral reefs through the coming centuries.

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